Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of	)	
	)	
Appropriate Framework for Broadband Access to the Internet over Wireline Facilities	))	CC Docket No. 02-33
	)	
Universal Service Obligations of Broadband Providers	))	
	)	
Computer III Further Remand Proceedings: Bell Operating Company Provision of Enhanced Services; 1998 Biennial Regulatory Review – Review of Computer III and ONA Safeguards and Requirements	)))))	CC Dockets Nos. 95-20, 98-10

DECLARATION OF RICHARD A. CHANDLER

I. QUALIFICATIONS.

1. My name is Richard A. Chandler. I am Senior Vice President at HAI Consulting, Inc., as I was at HAI's predecessor, Hatfield Associates, Inc.

2. I received BSEE and MSEE degrees from the University of Missouri in 1970 and 1971, respectively, and an MBA from the University of Denver in 1983. I also have completed additional graduate study in electrical engineering at the University of Colorado.

3. I have worked as an electronic engineer at the Institute for Telecommunication Sciences studying microwave and optical propagation and analyzing radar systems. I then worked at Bell Laboratories in the exploratory development of customer switching systems. While at Bell Labs, I worked extensively on packet switching and circuit switching technologies. I then transferred to AT&T, where I was a product manager working on, among other things, product strategies for packet switching systems. After working at AT&T, I joined a startup mobile satellite company

as vice president of network engineering. In that role, I developed the ground system network architecture, which included packet switching capabilities, for the proposed system.

4. At HAI (and Hatfield Associates, Inc.), I have been a principal developer of the Hatfield/HAI cost models. I have also analyzed a range of telecommunications technologies and systems for a number of clients. Many of these investigations have involved the study of packet switching technologies. I have, for example, worked extensively on packet radio techniques for a major international company engaged in package delivery service. I also worked as a technical advisor to a major Bell company wireless subsidiary, performing technical due diligence for its proposed acquisition of a European packet radio system. I have also taught graduate-level telecommunications technology courses in digital switching and other digital communications technologies, including transmission and packet switching, basic telephony, and cellular and wireless communications, at the University of Colorado, the University of Denver, and Pace University.

5. I have filed numerous affidavits and declarations concerned with telecommunications technology before this Commission, state regulatory agencies, and in Federal court cases, including testimony relating to DSL, packet switching, and circuit switching issues.

II. INTRODUCTION AND SUMMARY OF CONCLUSIONS

6. This declaration focuses on the development of communications transmission systems and technology. A review of this development underscores several fundamental points.

7. First, the evolution of loop transmission facilities and technologies has been and continues to be gradual. Beginning with the T1 transmission system introduced by the Bell System forty years ago -- and the Digital Subscriber Line (DSL) transmission technologies that have developed subsequently – technological advances have arisen from the fact that the inherent bandwidth of the copper loop, still used essentially without exception in distribution plant, can be

exploited by enhancements in the terminal equipment connected to it. The design of electronic equipment such as multiplexers and modems intended for use with loop facilities continues to improve by making better use of the inherent transmission capacity of loop facilities. Even with these advances, none of the loop transmission facilities described in this declaration – the T1 or the DSL systems in use today – performs end-to-end protocol conversions. Instead, these facilities convert signals from users into an appropriate form for transmission over the loop facility, and a complementary device at the far end of the connection converts the signal back into its initial form as transmitted by the subscriber's terminal device.

8. Second, throughout this period, vendors have attempted to develop and market equipment that makes the most efficient use of the incumbents' installed plant. Carriers have not replaced their plant to accommodate new electronic equipment designs. The most recent developments in loop transmission equipment design reflect these points. The installation of fiber deeper into loop networks that ILECs are considering reflects incremental, not fundamental, technological changes. Longer fiber runs would permit shorter copper distances and increased transmission speeds. Whether and when carriers use the capabilities inherent in fiber to provide broadband services depends not on advances in technology but on subscriber demand for higher-speed access and on incumbents' willingness to provide services to address subscriber needs. A wide-spread DSL system, ADSL, had been available but unused for years partly because of an intial lack of need, and because, after demand for high-speed internet access appeared, incumbents were reluctant to cannibalize their profitable second-line and T1 services.

9. Third, existing wholesale arrangements for broadband network elements have impeded competition in a number of respects. Existing and proposed wholesale prices for broadband loop rate elements are typically very high and sometimes well above the incumbent's corresponding retail price and forward-looking costs.

10. The balance of my declaration proceeds as follows. Section III provides technical

background, including an overview of the components of local telecommunications networks and a description of the technical characteristics of the existing loop plant. Section IV describes the evolution of digital loop transmission systems and technology. Finally, Section V discusses how current wholesale offerings of incumbent local exchange carriers (ILECs) have impeded competition for DSL-based services.

III. TECHNICAL BACKGROUND

11. This declaration addresses a range of technical issues pertaining to the transmission of various types of communications over traditional loop access facilities as they exist in the networks of ILECs. In particular, the following discussions describe the inherent capacity limitations and capabilities of the existing loop plant and explain how constantly-evolving signal processing techniques allow equipment developers to make increasingly efficient use of the existing capabilities of copper loops by improving the designs of the modems and multiplexers that attach to the loop.

12. Figure 1 provides a general view of the components of a typical ILEC network that carry voice and data traffic,[1] and the following paragraphs summarize the functions of each of the components.

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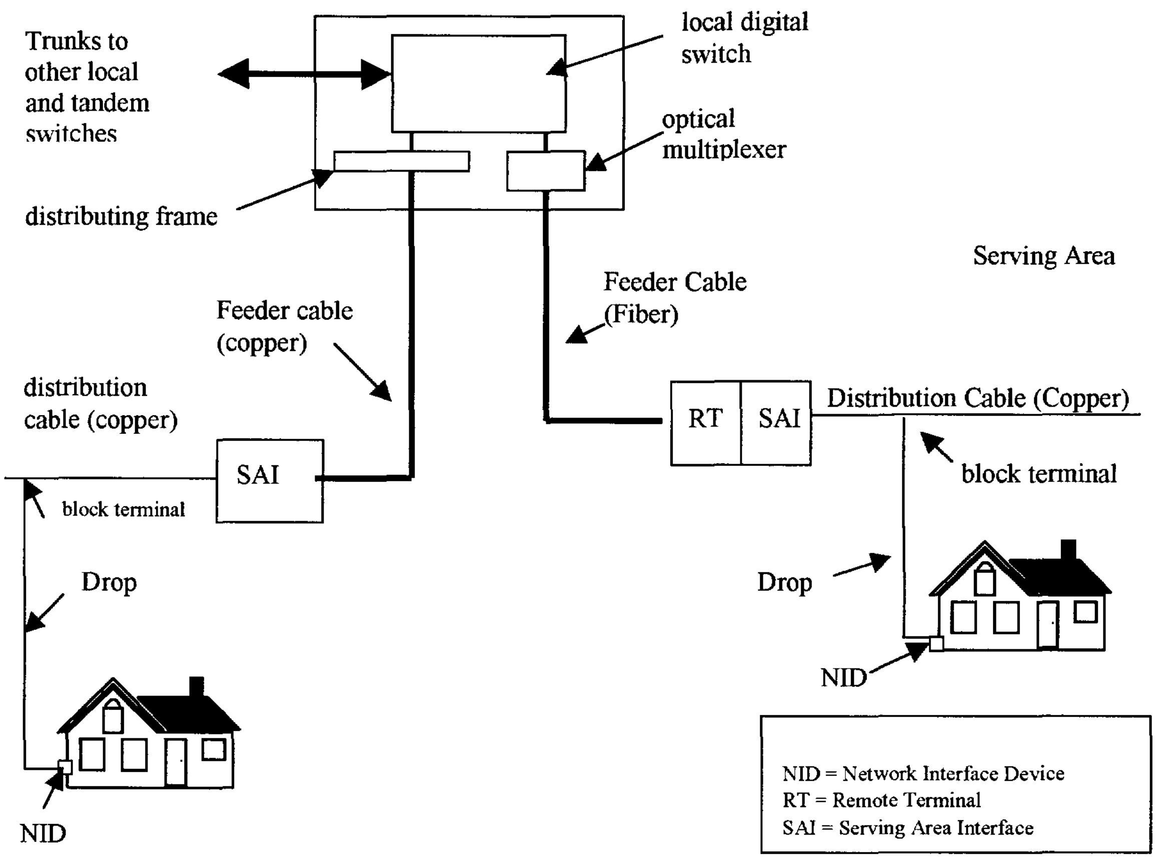
[1] There are other network components and functions that are not directly germane to this discussion, and they are not shown for reasons of simplicity. Several minor components have also been omitted in the interest of simplicity; their absence has no effect on this discussion.

FIGURE 1: LOCAL NETWORK LOOP COMPONENTS



Adapted from <u>Engineering and Operations in the Bell System</u>, 2nd Edition, 1983

13. A telephone subscriber connects with a local wire center (which usually contains a switching machine to provide dial tone and process telephone calls) over a dedicated loop connection. The loop facility consists of a number of components:

i. The network interface device (NID) terminates the ILEC's facilities at the customer's premises and marks the interface between the customer's premises wiring and the network.

ii. A short (usually tens of feet in length) service "drop" consisting of one or more copper wire pairs connects the NID to a distribution cable through a simple device called a "block terminal."

iii. The distribution cable, also consisting of a number of (possibly several hundred to a few thousand) copper wire pairs, runs to a cross-connect box, sometimes known as a serving area interface (SAI);[2] the distribution cable length is generally hundreds to several thousand feet.

iv. If copper feeder cable is used, the copper distribution pairs are connected at the SAI to copper feeder pairs which then extend to the wire center in cables consisting of hundreds to several thousand pairs over distances of hundreds to several thousand feet.[3] The feeder pairs ultimately terminate in the wire center at another cross connect, generically called a "main distributing frame," through which they are in turn connected to cable pairs which in turn connect with line

[2] The cross-connect function is a simple arrangement allowing any distribution pair to be connected to any feeder pair.

[3] This section describes a "forward-looking" network design. Earlier loop network designs also included digital loop carrier systems operating with copper feeder cables over one or more T1 connections.

interfaces, or "line circuits," on the switching machine (the "local digital switch") housed in the wire center.

v. If fiber feeder cable is used, the copper distribution pairs connect with short copper pairs which terminate on a nearby digital loop carrier (DLC) remote terminal (RT), which contains per-line analog to digital conversion devices called "codecs" (from coder/decoder) along with other loop interface components in circuit boards called "channel units," each of which usually serves several loops. The RT also includes a multiplexing function which combines several subscribers' signals into any of several high-bit-rate (1.544 Mbps, or DS-1) digital signals;[4] and a "time-slot interchange" function which allows the flexible assignment of subscribers' digitized voice signals to time slots in the multiplexed DS-1 digital bit streams carried over the feeder cable when it is required for service.[5] Finally, the RT includes optical transmitting and receiving devices for interconnection with the optical fiber strands in the feeder cable. The optical fiber feeder cable terminates in the wire center on an optical multiplexer which extracts the multiplexed DS-1 bit streams from the SONET signal. The DS-1 signals are in turn connected to a digital interface circuit integrated into the local digital switch.

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[4] The (possibly several) DS-1 signals are formatted into what is known as VT1.5 "virtual tributaries" which are then combined, or multiplexed, into a SONET (Synchronous Optical Network) format usually operated at the OC-3 (optical carrier level 3) rate of about 155 Mbps. This description again corresponds to a forward-looking network design in which the DLC equipment comports with Telcordia Technologies' GR-303 DLC requirements.

[5] This capability is referred to as concentration. It permits more subscribers to terminate on the RT than could be accommodated by the feeder capacity if all customers served by the RT were to demand service simultaneously. The local switch works with the RT to assign a feeder time

vi. The local digital switch provides dial tone to the subscribers it serves, processes calls and supports optional subscriber features, and connects with other local and tandem switches via transport facilities to route telephone calls to and from the local subscribers.[6]

This declaration is principally concerned with the transmission of signals over the copper loop components as described.

14. In discussing the technical aspects of how a signal is carried through a telecommunications network, it is useful to discuss the bandwidth required to transmit the signal so that it can be reproduced faithfully at the far end of the network.[7] The simplest example of an electrical signal is one whose amplitude varies over time in response to some input stimulus, such as an acoustic voice signal striking a microphone. A signal exhibiting relatively fast changes in amplitude over a given amount of time occupies a wider spectrum than one with slower amplitude changes over the time period. A common speech signal, for example, a relatively slowly-varying signal (in comparison with other types of signals commonly encountered in telecommunications) occupies a bandwidth of a few thousand Hertz. Telephone network components (such as the codecs mentioned above) limit the effective voice bandwidth to a range typically extending from 200 to 3200 Hz.[8]

15. Short pulses and other signals exhibiting rapid amplitude changes occupy a wider

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slot to a customer when the customer demands service. The time slot is released when the customer's service is no longer active.

[6] In the integrated DLC case, the DLC system effectively moves the line circuit, or line interface, from the local digital switch to the RT. The switch still provides dial tone and all call processing functions but circuitry in the RT delivers dial tone and ringing current to the individual subscriber.

[7] The term "bandwidth" is used in its correct engineering sense as the amount of the electromagnetic spectrum, expressed in Hertz, occupied by a signal. The increasingly popular notion of bandwidth expressed in bits per second is incorrect and, for good technical reasons, is useless in accurate discussions of signal transmission.

[8] Bell Laboratories, *Transmission Systems for Communications*, 1982, p 32.

bandwidth than more slowly-varying signals and as a result require more of a transmission system's available spectrum. If the signal bandwidth exceeds that of the transmission facility, the signal will be distorted in transmission, possibly fatally. Especially in the area of digital transmission, equipment designers can employ a number of techniques to design signals so that they occupy a given bandwidth. All other things being equal, signals carrying more information occupy more bandwidth than those carrying less information. A telephone speech signal thus occupies a narrower bandwidth (3 kHz) than, say, an FM radio program signal (15 kHz). Signal design and processing techniques for transmitting high-speed (high information rate) digital signals over limited bandwidths continue to evolve and are very sophisticated.

16. *Analog* signals continuously vary in time. The amplitude (often expressed as a voltage) of a telephone speech signal, for example, varies directly with the changes of the sound pressure of the acoustic voice signal applied to a microphone in the telephone set and thus is an electrical representation of the original acoustic signal. *Digital* signals are numeric representations of the input signal which has been encoded in some prescribed fashion by devices such as codecs. These signals are transmitted as discrete symbols. In binary digital transmission (the simplest form of digital communications), the transmitted symbol can assume either of two states, one of which represents a logical "1" and the other a logical "0." In higher-level digital transmission schemes, symbols may assume any number of states, although the number is usually an integral power of two (four, eight, sixteen, and so forth). The symbol transmission rate is known as the "baud rate," and, for binary transmission, the baud rate is the same as the end-to-end bit rate. If a four-level symbol is used, each symbol represents two bits, and the end-to-end bit rate is twice the baud rate in the transmission system. The higher the baud rate, the higher the transmitted information rate. Multilevel symbols, when properly designed, can make more efficient use of the available spectrum (by increasing the number of bits per second carried per unit of bandwidth) and are extensively used in high-speed digital (and particularly wireless) communications.

17. The twisted wire pairs used in telephone loop transmission generally have a much wider transmission spectrum available than that required for voice signals.[9] A rigorous technical analysis of the transmission characteristics of copper loops is very complicated. The principal characteristics of loop transmission as they apply to the available spectrum, however, can be fairly easily summarized.

18. A pair of closely-spaced electrical conductors, such as a copper telephone loop, reflects a set of characteristics or parameters – resistance and inductance along each conductor, and capacitance and conductance between the conductors. Of these, the distributed resistance is usually the most familiar. Electrical resistance impedes the flow of electrical current and does so independently of frequency. The longer the loop, the greater the resistance, and the more difficult it is to send a signal of any frequency content through it. Because resistance is independent of frequency, resistance attenuates all frequencies the same amount and thus does not distort a signal by reducing signal levels more at one range of frequencies than another.

19. An electrical charge moving through a conductor (the current) generates a magnetic field around the conductor, and the magnetic field tends to oppose any change in the current. This effect is characterized by the distributed inductance in each of the conductors. Inductance impedes the flow of any current, or signal, having a frequency greater than 0 Hz. The higher the frequency, the stronger the effect. Also, longer conductors have a greater inductance than shorter ones, so that longer loops have correspondingly greater difficulty in transmitting higher frequencies. Inductance thus leads to signal distortion, because it affects higher frequencies

[9] This discussion pertains to loops that do not have loading coils installed. Loading coils, when present, restrict the usable loop spectrum roughly to the voiceband frequencies, or below about 3500 Hertz. *Id.*, p 225. As this discussion explains, very long copper loops distort voiceband signals by attenuating, or weakening, higher-frequency signals much more than lower-frequency signals. Loading coils are designed to mitigate this effect by "flattening" the loop's frequency response, the removing the frequency-dependent attenuation and attendant distortion. Other loop impairments, such as bridged taps, can degrade the transmission of higher frequency loop signals as well, particularly those that lie above the voiceband.

more strongly than lower ones.

20. The proximity of the two conductors in a twisted-pair loop also gives rise to an effect known as "capacitive coupling" between the conductors which affects signals containing frequencies above 0Hz. This causes an effective electrical "leakage" between the conductors, and the coupling effect increases with increasing frequency. The effect is more pronounced for longer loops, because the total capacitance between the conductors is greater than it is for shorter loops. The capacitance also distorts signals, again because it affects higher frequencies more than lower frequencies. Conductance, like resistance, is not a function of frequency and leads to frequency-independent leakage between conductors. The amount of conductance between wires in a twisted pair is negligible in modern telephone loop facilities.

21. The combined effects of the distributed series inductance and shunt capacitance in a copper loop cause higher frequencies to be attenuated more strongly than lower frequencies, and this phenomenon is more pronounced at longer loop lengths.[10] Thus, the available spectrum of a copper loop decreases as the loop length increases. Even at that, an 18,000 ft copper loop still exhibits a usable bandwidth well beyond the voice band.

22. Many technological advances in telecommunications over the past forty years arise from the fact that the inherent bandwidth of the copper loop can be exploited by the terminal equipment connected to it. Although there have been profound improvements over the past twenty years just in the use of the voiceband spectrum on copper loops,[11] the transmission medium has clearly not changed. Instead, signal processing and related design techniques and technologies have improved to make much more efficient use of the existing plant. I expand this notion in the next sections.

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[10] This discussion applies only to the transmission of electrical signals over copper loops and not to optical signals over optical fiber cables.

[11] For example, today's V.90 modems can transmit and receive data signals operating at end-to-end rates of as high as 50 kbps (or even slightly higher) in the same bandwidth (the voice band) that early modems such as the Bell 103 Data Set required to transmit 300 bps.

23. Finally, there is no technical basis for the FCC's 200 kbps dividing line between "broadband" and "narrowband" service. The definition of the term "broadband" has always been somewhat fluid, although until very recently it has almost never included rates as low as the 1.544 Mbps DS-1 rate. In the past, rates from DS-1 up to the old DS-4 rate of 274 Mbps were considered "wideband" by Bell Laboratories;[12] other informal usage has considered rates of tens to hundreds of megabits per second as "broadband."[13] The FCC has chosen to define the "broadband" threshold as 200 kbps. From a technical point of view, this definition is entirely arbitrary. There is, in fact, no substantial technical difference between equipment operating at the 160 kbps basic ISDN loop rate and HDSL equipment operating at the DS-1 rate, although, by the Commission's definition, one is "narrowband" and the other "broadband."

IV. THE DEVELOPMENT OF DIGITAL LOOP TRANSMISSION

A. The T1 Transmission System: The First Digital Transmission System

24. The T1 transmission system was the first digital transmission system in the North American switched network and was designed to take advantage of the inherent bandwidth of twisted wire pairs.[14] The Bell System introduced T1 about forty years ago as a short-haul, intracity transmission system to provide digitally multiplexed trunk connections between wire centers. At the time, intracity trunks consisted of wire pairs (depending on the type of trunk, either one or two pairs were used), and equipment developers at Bell Laboratories recognized that high-bit-rate digital signals could be sent over these facilities if the signals were properly

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[12] *Id.*, p. 161.

[13] "Broadband" ISDN, for example, usually refers to the OC-12 rate of 622 Mbps extended to the subscriber's premises, while "narrowband" ISDN refers to a subscriber line rate of 160 kbps.

[14] The term "T1" refers specifically to a digital transmission system of a particular design that operates at the rate of 1.544 Mbps, known as the "DS-1" rate. DS-1, in turn, originally referred to a bit rate and nothing more. It is the lowest rate in the old so-called North American digital hierarchy which ranged from DS-1 up to DS-4, a rate of about 274 Mbps. The extremely high rates made possible by the SONET standards, among other things, rendered the older hierarchy obsolete.

designed.[15] This opened the possibility of combining (multiplexing) a number of voice signals, each digitally encoded at a bit rate considerably less than that of the facility itself, into a single, relatively high-speed, digital signal carried by a single pair of wires which previously carried only a single analog voice signal. A second pair of wires was also required for two-way transmission. In practice, the classical T1 system digitized each of twenty-four voice signals at a rate of 64 kbps and multiplexed them into a single stream at a rate of 1.544 Mbps (24 x 64 kbps), including an 8 kbps overhead signal used for synchronizing the transmitting and receiving terminal equipment.[16]

25. Beginning around 1980, T1 service was extended to business customers' premises using fundamentally the same technology that was developed for the original interoffice application. A conventional T1 installation to a customer requires considerable engineering and installation effort to select and test wire pairs, install regenerators as required, and install and test terminal equipment at both the customer's end of the circuit as well as in the serving wire center.

B. The Evolution Of Digital Subscriber Line Transmission Systems

26. Over the past two decades, the loop plant has undergone evolutionary change, with the primary aspect being increasing amounts of optical fiber cable in the feeder plant. Distribution plant remains almost universally copper, but incumbents have added fiber feeder in new construction and in areas in which existing copper feeder routes need to be reinforced in

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[15] The developers settled on a binary and bipolar line code in which a logical 1 is sent as a short pulse and a logical 0 is represented by the absence of a pulse in a bit period. Consecutive 1's are represented by alternating positive and negative pulses, hence the term "bipolar." The pulse shape was chosen to cause the transmitted signal to occupy as little bandwidth as possible. Among other things, the relatively narrow spectrum increases the average distance the signal can travel without being regenerated.

[16] K.E. Fultz and D.B. Penick, "The T1 Carrier System," *Bell System Technical Journal*, Vol 44, pp. 1405-1451, September, 1965. A peculiar term, "analog T1," has arisen in some quarters to refer to conventional T1 transmission technology. This is patently incorrect: T1 is inarguably digital, as it transmits digitally-encoded representations of analog waveforms via a set of discrete symbols (which are binary, in the case of T1).

capacity. Depending on local circumstances, incumbents may install copper feeder cables instead of fiber in new construction, particularly if the new feeder route is to serve customers with short overall loop lengths. Nevertheless, an incumbent may have strategic reasons for installing fiber feeder even when copper feeder would be perfectly adequate for voice service.

27. Deployment of fiber feeder cable requires the use of digital loop carrier (DLC) technology to carry signals digitally over the fiber feeder facility and to make the appropriate analog to digital (and digital to analog toward the subscriber) conversion at the feeder/distribution interface along with a conversion between optical and electrical signals. DLC systems can also use copper feeder facilities, but modern, or "next generation" (NGDLC), systems generally use fiber feeder cable operating at the SONET OC-3 rate (nominally 155 Mbps). Depending on the application, higher SONET rates or wavelength division multiplexing techniques are used to increase the feeder capacity.[17]

28. DLC systems using fiber feeder cable still transmit the feeder signals as one or more DS-1 signals, just as they would if they used copper feeder cable. Telcordia's integrated DLC requirements, GR-303-CORE, call for the feeder connection to consist of a number of discrete DS-1 signals, which can be carried over copper pairs or, preferably, as DS-1 virtual tributaries in a SONET signal carried on optical fiber.[18] The feeder transmission medium is thus transparent to the end-to-end voice and data signals carried over the subscriber connections, and the selection of optical fiber or copper feeder cable just represents an economic choice made by the carrier.

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[17] These optical transmission techniques are well-proven. They first appeared in long-haul networks and somewhat later in intracity networks. As equipment and component prices have fallen, these techniques have become increasingly attractive for use in loop transmission systems. They thus do not represent new or advanced technological developments.

[18] These requirements are described in Telcordia Technologies, *Integrated Digital Loop Carrier System Generic Requirements, Objectives, and Interface,* GR-303-CORE, Issue 1, September 1995, Revision 2, December 1996, and later revisions.

29. The evolution of loop transmission facilities and technologies has been and continues to be gradual. Distribution plant is without exception copper, and feeder facilities may consist of copper or fiber cable. The design of electronic equipment such as multiplexers and modems intended for use with loop facilities continues to improve so as to make better use of the inherent transmission capacity of loop facilities. It is important to recognize that development efforts by transmission equipment vendors are precisely as stated in the previous sentence: Vendors strive to develop and market equipment that makes the most efficient use of the incumbents' installed plant. Carriers do not replace their plant to accommodate new electronic equipment designs.

30. Digital Subscriber Line (DSL) transmission systems have their roots in the original DSL developed for the transmission of basic rate ISDN (Integrated Services Digital Network) signals over copper loops. The goal of ISDN was to provide end-to-end digital network services using the existing loop plant. A basic rate ISDN loop carries simultaneous 160 kbps signals in both directions. This transmission rate requires that the loop be free of loading coils, and a number of technical innovations were required to allow bi-directional transmission over a single wire pair at these bit rates. The principal "enabling" techniques are digital echo cancellation and adaptive, or automatic, equalization of line impairments such as signal reflections caused by bridged taps.[19] Echo cancellation is necessary to remove reflected components, or echoes, of transmitted signals at the inputs to receivers at either end of the loop. Commercial deployment of this equipment required the availability of affordable digital signal processors and other silicon-based components having suitable performance characteristics.

31. As was the case with ISDN, current DSL technologies such as ADSL, HDSL, and others are designed to use the inherent capacity of the existing loop plant by applying increasingly sophisticated signal processing techniques to the equipment sending and receiving signals over the loop. All of these terminal devices are modems: They convert signals from users into an

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[19] The "advanced signal processing techniques" for loop transmission equipment as discussed throughout this declaration refer to these echo cancellation and adaptive equalization functions.

appropriate electrical form for transmission over the loop facility, and a complementary device at the far end of the connection converts the signal back into its initial form as transmitted by the subscriber's terminal device.

32. DSL technologies such as HDSL (high bit rate digital subscriber line) may be classified as "baseband" technologies, because the transmitted signals consist of electrical pulses of discretely-varying amplitude and whose spectrum extends from just above 0 Hz across the entire voice band up to a few hundred kiloHertz. HDSL signals thus cannot coexist on a loop with voiceband, or POTS, signals. The HDSL supports T1 transmission between the customer's premises and the serving wire center using HDSL terminal units (HTUs) at either end of the loop facility. For DLC-served loops, HDSL channel units are available for HDSL transmission over the copper distribution plant between the customer location and the DLC remote terminal. The HTUs convert the T1 signal at either end of the connection to four-wire bi-directional transmission over the copper loop.[20] The HTUs thus function as specialized modems, and they incorporate echo cancellation and automatic equalization functions to allow operation over nonloaded loops without the need for specialized engineering and installation practices. Installation of HDSL equipment is thus usually much simpler, and hence much cheaper, than installation of a conventional T1 system. HDSL signals also can travel up to 12,000 ft (and sometimes farther, depending on the equipment vendor) without regeneration, assuming suitable loop characteristics. The presence of HDSL is transparent to the user. A customer requiring T1 service can be served interchangeably by conventional T1 or HDSL loop technology with no effect whatsoever on the customer's terminal equipment or overall service level.

33. Other baseband DSL technologies have been developed in the past few years. One of these, g.shdsl, is designed to allow bi-directional transmission over a single wire pair at rates up

[20] Conventional T1 systems use one pair for each direction of transmission, with each pair carrying the signal at the full DS-1 rate. HDSL transmits a half-rate signal bi-directionally on each pair of the four-wire loop.

to about 2 Mbps, including the DS-1 rate. These technologies, like HDSL and other forms of DSL, are designed to exploit the capabilities of advanced signal processing techniques to allow high-speed transmission over existing and unmodified loop facilities using specialized modems. ADSL (asymmetric digital subscriber line) may, in engineering terms, be considered a "high pass" technology in that ADSL signals use loop spectrum that lies above the voice band. ADSL signals thus can occupy a subscriber loop simultaneously with analog voiceband signals. A "splitter" is required at the wire center end of the ADSL-equipped loop to separate the POTS signal from the high-frequency spectrum carrying the high-bit-rate signal. Figure 2 shows how the splitter divides the low-frequency POTS and the high-frequency digital signals: the splitter consists of filtering functions which prevent the high-frequency signal from appearing at the local switch line interface and the POTS signal from appearing at the DSLAM (digital subscriber line access multiplexer).[21] The application of appropriate signal processing techniques (once again, echo cancellation and equalization of deleterious loop characteristics) allow the transmission of upstream rates (from the subscriber) of hundreds of kilobits per second and downstream rates (toward the subscriber) of possibly a megabit per second or more, depending on the version of ADSL in use and on loop characteristics. As is the case with HDSL and other forms of DSL, the sophisticated ADSL modem design allows such high-bit-rate transmission on unloaded loops usually without any attention from an incumbent's installation or maintenance force. A prevalent form of ADSL, g.lite (or ITU-T G992.2), does not require the installation of a splitter at the customer's premises (and hence a visit from a member of the carrier's installation

[21] A splitter is a simple electrical filtering device consisting of passive components (inductors) that separates the voiceband POTS signal from the high bit rate signal occupying the high-frequency spectrum of the loop so that the POTS and data signals can be independently connected to different networks although a single loop facility connects to the customer premises. At the customer's premises, a splitter is used with so-called "full-rate" ADSL to restrict communications generated by telephones, answering machines, facsimile machines and similar devices to the voiceband (low frequencies), and restrict communications requiring high-rate bit streams, such as ADSL modems, commonly installed in a computer, to the high frequency spectrum of the loop (i.e., above voiceband). In the case of G.992.2-based ADSL, the retail customer installs an in-line low-pass filter at each telephone set (on inside wire shared with the ADSL modem) to reduce the "hiss" caused by the high-frequency data signal.

force) and allows upstream transmission up to 256 kbps and downstream to 1.5 Mbps. Incumbents offering G992.2-based ADSL usually mail an ADSL modem, along with software and instructions, to new subscribers who then handle their own installation.

34. ILECs have used the loop spectrum above the voice band for years to carry "derived" additional voice channels. A notable example of this is the use of DAML (digitally added main line) techniques which allow a single non-loaded two-wire loop to carry two voice signals simultaneously, one in the standard voice band and the other as a digitally-encoded signal carried in spectrum above the voice band. Charles Industries, for example, has provided Sprint with DAML products for a number of years.[22] More advanced equipment is now available that allows several voice channels and a symmetric data channel to be carried on a two-wire loop using advanced DSL techniques. Charles Industries has a g.shdsl-based[23] product, HVDL 3.1, capable of providing three voice lines and a 1.04 Mbps data connection on single-pair loops over distances of up to 56,000 ft with repeaters.[24]

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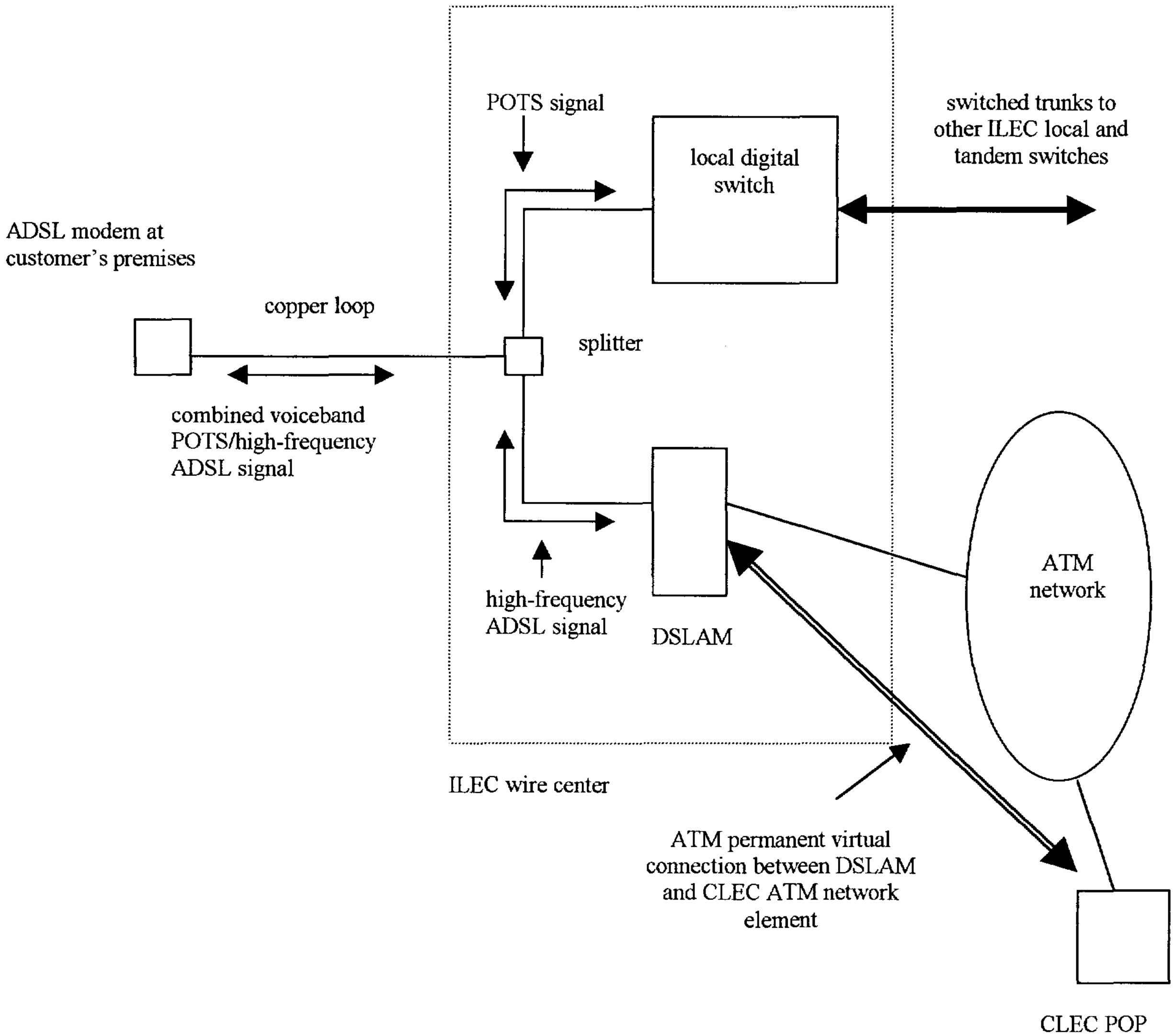
[22] Charles Industries white paper, "DSL in Pair-Gain/DAML Regions – Technical Analysis & Recommendations," August 7, 2001, p 2.

[23] This is a relatively new international standard (ITU G991.2) for symmetric DSL on one pair specifying data rates up to about 2 Mbps.

[24] Charles Industry white paper.

FIGURE 2: NETWORK COMPONENTS AND ATM CONNECTIONS FOR ADSL ON COPPER LOOPS



35. Finally, the most recent developments in loop transmission equipment design likewise reflect incremental, not fundamental, technological changes. ILECs are currently considering installation of fiber deeper into loop networks. Longer fiber runs imply shorter copper distances, allowing higher bit rates. Development of commercial products will be driven ultimately by subscriber demand for higher-speed access and directly by incumbents' willingness to provide services to address subscriber needs. No fundamental technological advances are required to achieve these increased transmission speeds;[25] the reduced copper distances mean that a wider usable loop spectrum is available for equipment developers to use for higher bit rate modem designs. VDSL (very high bit-rate digital subscriber line) is an example of a loop transmission technology designed to operate over fiber feeder facilities with very short (a few hundred to a few thousand feet) distribution distances. VDSL is conceived essentially as an enhanced form of ADSL and allows downstream transmission of possibly a few tens of megabits per second, upstream transmission of one or two megabits per second, and simultaneous POTS usage. The tradeoff is simple: higher per-subscriber transmission rates are achievable with shorter copper runs which in turn are enabled by deeper fiber penetration at increased plant investment.

36. Incumbents will choose to deploy these incrementally-improved systems, however, only when there will be a net gain for the enterprise. Thus, in making investment decisions with respect to evolving technology, ILECs will consider what effects such investments will have on the ILECs' currently deployed network and services. ADSL technology, for example, had been available but unused for years partly because of an initial lack of need and because, after demand for high-speed internet access appeared, incumbents were reluctant to cannibalize their profitable second-line and T1 services. Given their enormous investment in existing plant, incumbents will focus their efforts on incremental advances in their networks, rather than "field of dreams" approaches to network deployments, such as fiber-to-the-curb.

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[25] It is, however, necessary in such shared-feeder cases that more sophisticated multiplexing techniques be employed on the fiber feeder segment of the system to allow the capabilities of the copper distribution pairs to be fully exploited.

C. None Of These Loop Transmission Technologies Performs End-to-End Protocol Conversions

37. Another point common to all of the transmission technologies I have been describing is that none performs end-to-end protocol conversions. As was noted for HDSL, the HTU modem pair delivers a T1 signal to the customer at a standard interface level, just as a conventional T1 transmission system would deliver an identical signal.

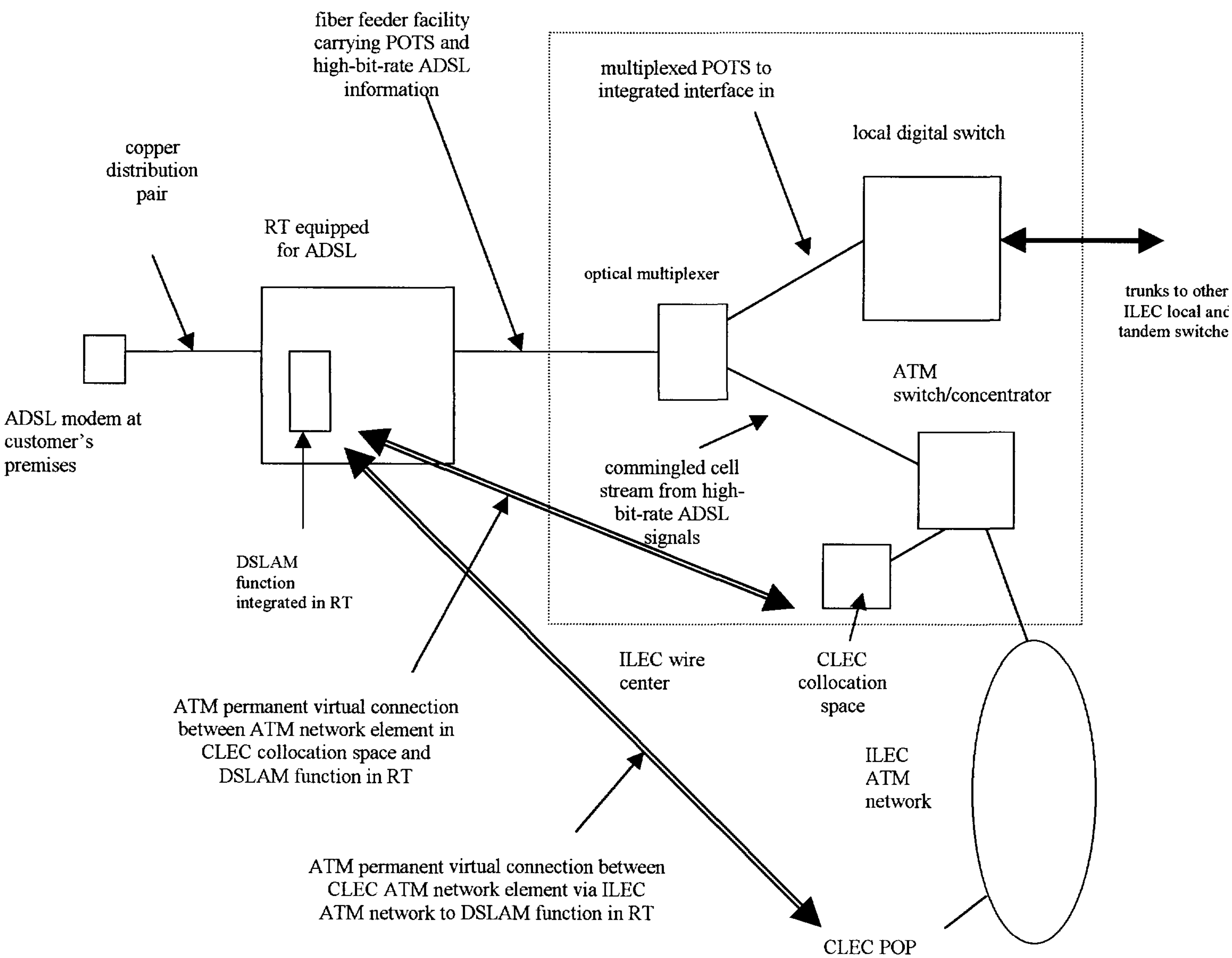
38. ADSL is another useful example of the fact that these advanced modem-based loop transmission technologies do not perform end-to-end protocol conversion. ADSL modems are designed to interface with IP (Internet Protocol) devices, such as subscriber computers equipped with Web browsers, because the connection will terminate at an Internet service provider's (ISP's) point of presence. Most ADSL network components use ATM (Asynchronous Transfer Mode) transmission and routing, so that the customer's IP-based transmissions must be encapsulated into the ATM stream carried over the ADSL part of the connection and through an ATM network to the ISP's POP. The ISP then recovers the customer's IP transmission. Thus, what is delivered to the ISP is in the same form that was transmitted by the customer's terminal device (computer), and no end-to-end protocol conversion has happened.

V. EXISTING ILEC WHOLESALE ARRANGEMENTS FOR BROADBAND NETWORK ELEMENTS IMPEDE COMPETITION IN A NUMBER OF RESPECTS

39. ILEC wholesale arrangements for broadband rate elements generally consist of at least two major components: the DSL-equipped loop and a packet network connection between the DSLAM and the CLEC's location. Figure 2 shows these network components. The DSLAM in the wire center connects with an ATM (Asynchronous Transfer Mode) network element, usually over a dedicated transport connection at the DS-3 or OC-3 rate. In the case of a DLC-served loop, the DSLAM function is located in the RT, as shown in Figure 3, and the ATM connection extends to the components in the RT that perform the DSLAM function directly, possibly

through an ATM device located in the wire center adjacent to the multiplexer terminating the fiber feeder connection.

FIGURE 3: NETWORK ELEMENTS AND ATM CONNECTIONS FOR ADSL ON DLC-SERVED LOOPS



40. Packet switching is a technique originally designed for the efficient transmission of data. User data are encapsulated into discrete packets for transmission. Packet switching efficiency results from the fact that network capacity is requested only when there are packets awaiting transmission. In many applications, such as web browsing, users only occasionally transmit and receive data. ATM is a form of packet switching[26] designed to accommodate, in addition to interactive data, a range of disparate types of transmission such as voice and video. Thus, ATM packets, known as "cells," carry digital representations of voice, data, and video signals over common facilities in an interspersed fashion. The ATM Forum defines a set of service classes which together support the broad range of services that ATM addresses.[27] There is a corresponding set of quality of service (QoS) parameters that specify the level of service to be provided by each service class, and the ATM Forum provides precise definitions of how the cells carrying the various types of service are to be combined on a common transport facility to satisfy the QoS guarantees for each service. I will discuss examples of the service classes below.

41. ATM is a "connection-oriented" form of packet switching, meaning that a logical association, usually called a virtual circuit or virtual channel, is required between the endpoints of the connection. The term "virtual" is key in this context. Once the virtual channel is established, the network then knows to send all packets generated at one end point to the other end point in the virtual connection. The virtual circuit is just the association of the endpoints of the connection and does not imply anything about network capacity. Packet switching systems make capacity available only on demand. Thus, there is no capacity dedicated to the virtual connection as there is in the physical connection in the circuit-switched case. If the end points of the virtual connection are idle, nothing is transmitted over the virtual connection. When one end or the other has information to transmit, the corresponding packet network interface uses a

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26 ATM, as it is applied in the local loop, is purely a transmission mechanism and not a switching function. It is employed because of its ability to transmit data and other types of communications efficiently.

27 The ATM Forum is an industry group that develops and defines ATM standards. http://www.atmforum.com/

precisely-defined "multiple access" procedure to acquire temporary access to the network capacity to transmit the packets. Because ATM in the loop application is a transmission mechanism transparent to the subscriber, it is no more and "advanced service" than is GR-303.

42. The most prevalent type of virtual circuit used in practical ATM applications such as transport and routing of ADSL signals is established through an administrative process and is termed a PVC, or "Permanent Virtual Channel."[28] In Figure 3 showing the typical arrangement of ILEC network components for wholesale DSL arrangements, at least one PVC must be established over the ATM network between the DSLAM function and the CLEC's appearance on the ATM network. A PVC, along with network capacity, forms the transport part of the wholesale arrangement.

43. Existing and proposed wholesale prices for broadband loop rate elements are typically very high and sometimes well above the incumbent's corresponding retail price. As an example, Qwest recently proposed unbundled ADSL/packet switching wholesale rates in its region. The combined wholesale rate proposed for Arizona is \$45.48 per month.[29] Qwest offers unbundled retail ADSL service (with no ISP) for \$21.95 per month ("Qwest DSL 256," which provides service at 256 kbps downstream and up to 256 kbps upstream) and \$31.95 per month ("Qwest DSL Deluxe," which offers up to 640 kbps downstream and up to 256 kbps upstream).[30] Qwest's wholesale rates are 107% and 42% higher than the retail prices.

44. These wholesale rates are also far above forward-looking costs. AT&T, for example,

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[28] The ATM Forum also defines switched virtual connections that are established in response to end-user signaling procedures. Such switched connections are not as widely-used as PVCs. The PVC is akin to the permanent connection established in a digital cross connect system (DCS), with the important distinction that the PVC does not involve dedicated circuit capacity, as does the DCS connection.

[29] *See* Direct Testimony of Richard Chandler, *In The Matter Of Investigation Into Qwest Corporation's Compliance With Certain Wholesale Pricing Requirements For Unbundled Network Elements And Resale Discounts*, Arizona Corporation Commission Docket No. T-00000A-00-0914, May 16, 2001, p. 17.

[30] http://www.qwest.com/residential/products/dsl/index.html

filed forward-looking costs in Minnesota using the HAI xDSL Adjunct Model showing that Qwest's DSLAM plus ATM transport monthly cost per subscriber was $8.20 per month.[31]

45. Even if a reseller were to sign up for an ILEC's wholesale broadband loop offerings, the reseller would soon find that the levels of service available at these premium prices are narrowly restricted. Both SBC and Qwest explicitly restrict their wholesale offerings to the lowest ATM service class.[32] This class, UBR (Unspecified Bit Rate), is sometimes described as a "best-effort" service and carries with it no service quality guarantees. UBR cells carry the lowest priority in an ATM network. Thus, for example, the effective data transmission rate and the delays packets encounter as they travel through the network can and will vary, and the underlying service provider (the ILEC) makes no guarantee regarding the variation of either rate or delay. UBR is useful for applications such as casual Internet access in which variable cell delays are not critical and which do not require quality of service guarantees. It is unsuitable for packet voice, video, circuit emulation (such as DS-1 service) or other more sophisticated applications.

46. Other ATM service categories are available to serve such applications. As an illustrative example, real-time Variable Bit Rate (rt-VBR), is designed to support such services as packet-switched voice communications. Voice service is particularly sensitive to end-to-end delays in transmission as well as to variations in the end-to-end delay. Excessive delay can lead to "echoes" over a circuit which can be disorienting if the delay is sufficiently long, and unacceptable variations in delay can lead to difficulties in reconstructing the analog signal at the destination. The rt-VBR service category is designed to support such delay-sensitive applications and carries with it service guarantees that ensure a suitable quality of service.

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[31] *See* Direct Testimony of Douglas Denney, *In Re Commission Investigation of Qwest's Pricing of Certain Unbundled Network Elements*, Minnesota Public Utilities Commission Docket No. P421/CI-01-1375, March 18, 2002, p. 2-20.

[32] SBC Tariff, 1st Revised Sheet 63; "Qwest DSL Services," Qwest Communications International, Inc., Technical Publication 77392, Issue H, May, 2001, p 2-20.

47. To continue this illustrative example, if rt-VBR were made available to CLECs under ILECs' broadband wholesale arrangements, competitors could offer high-quality packetized voice service over DSL connections. A competitor could also offer advanced video services using ATM service categories with guaranteed quality of service levels. The incumbents' artificial service constraints thus impede the development of such innovative services by restricting competitors' access to a wider range of ATM service categories.

VI. CONCLUSION

47. I conclude the following:

- The evolution of loop transmission facilities and technologies has been and continues to be gradual. The existence of "excess" capacity, or bandwidth, of copper loops beyond that required to transmit voiceband signals has long been recognized and has been exploited over the years by the development and deployment of increasingly sophisticated modem and multiplexing equipment connected to copper loops. Although the signal processing techniques employed by this equipment have steadily evolved, the devices themselves are still fundamentally modems and multiplexers.
- Even with this evolution, high-bit-rate loop transmission systems and, as appropriate, corresponding interoffice transport components, still do not perform end-to-end protocol conversion. Even though conversions to and from ATM or other forms of fast packet switching may occur within the system, the form of the signal delivered on the far end of the connection is the same as the user signal originally transmitted.
- Vendors have attempted to develop and market equipment that makes the most efficient use of the incumbents' installed plant. Carriers have not replaced their plant to accommodate new electronic equipment designs. Thus, although higher-performance modems and multiplexers based on incrementally-improved signal processing techniques (such as those used in VDSL) could be developed and deployed, such development and deployment will

occur only if they are economically attractive to carriers and address subscribers' demonstrated needs for higher-speed access than that now afforded, for example, by ADSL and HDSL. No dramatic technological advances are required to make such equipment available commercially – it exists today.

- Current ILEC wholesale arrangements for broadband are typically priced well above their forward-looking costs and often even well above ILECs' corresponding retail services. At best, the types of service available under these arrangements are restrictive and can constrain resellers from offering end-user services beyond simple internet access. More likely, they will serve only to limit the pace of advanced service deployment by non-ILECs and deny consumers the choice of alternative services. They further will reduce the likelihood that alternatives to second-line services and inexpensive voice services will be deployed except on a schedule determined by the incumbent.

VERIFICATION PAGE

I hereby declare under penalty of perjury that the foregoing is true and accurate to the best of my knowledge and belief.

April 27, 2002